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Interspersed Salt-Affected and Unaffected Dryland Soils of the Lower Rio Grande Valley: II. Occurrence of Salinity in Relation to Infiltration Rates and Profile Characteristics[1]

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ABSTRACT

Thirteen variables including chemical and physical characteristics, topographical features, and water table depth measurements were statistically analyzed for differences between seven saline and adjacent nonsaline soil profiles of Lower Rio Grande Valley salt-affected dryland soils. Cumulative intake and final intake rate, electrical conductivity of soil saturation extract, exchangeable sodium percentage, clay percentage, relative elevation, sand percentage, soil surface slope, and cation-exchange capacity were the variables most consistently different between saline and nonsaline soils. Profile salinity and water intake were both significantly correlated with profile sand and clay content and with soil surface elevation. In addition water infiltration was a function of profile salinity. Consideration of the effects of clay content, ground surface elevation, and soil slope on the processes of runoff and infiltration lead to the conclusion that the observed salinity pattern is due to differential infiltration of rainfall which results in differences in leaching between saline and nonsaline areas.

In the nonirrigated eastern part of the Lower Rio Grande Valley of Texas, naturally occurring saline soil is interspersed among nonsaline soil in a very irregular pattern. The area is underlain by a regional water table which fluctuates with rainfall and crop use (R. R. Allen and L. Lyles, *Unpublished data.*) Extent of the affected soil is in the order 150,000 to 200,000 acres (5, 6). In such an area where the only water available for leaching is rainfall, the balance between evapotranspiration induced upward water flow and the downward flow of infiltrating water becomes critical.

Limited solar energy restricts the upward flux of soil moisture to a maximum of about 1 cm/day. On the other hand, because of the usual limited duration but high intensity of rainstorms the infiltration rate must be of the order 2 to 3 cm/hour for the rain water to infiltrate the soil where it falls. Furthermore, infiltration rates might deviate widely from the cited value whereas upward moisture fluxes or the same sites do not. Since differences in leaching occur in accord with differences in infiltration rates, the occurrence of salinity should be associated with the infiltration rate at the site.

It was hypothesized that there is a direct relation between the occurrence of salt-affected sites and the infiltration rate at those sites. This study was designed to test this hypothesis.

The influences on intake of water by soil are numerous and include vegetal cover and stability of the surface; characteristics of the soil mass or profile such as pore size and effectiveness, bulk density, colloid swelling, and depth or thickness of the permeable portion; antecedent moisture conditions; duration of water application; and, temperature of the soil and water (3, 8, 10, 11). For this reason surface topography and physical and chemical characteristics of soil profiles were investigated for possible relation to water infiltration rates and salinity occurrence.

METHODS AND MATERIALS

Infiltration determinations were made in seven cultivated fields. In each field quadruplicate infiltration determinations were made in the center of the bare saline area and nearby in the same field where crops exhibited no apparent detrimental effects of salinity.

The infiltrometers used were constructed of 1-inch by 10-inch redwood lumber and were 3 feet square. The lower edge of the infiltrometers was recessed about 3 inches below ground level. This position was achieved by carefully trenching around the 3-foot-square infiltration area and lowering the infiltration box over this undisturbed soil "island." Following infiltrometer placement the narrow trench outside the infiltrometer and the "crack" between the inside of the infiltrometer and the soil were filled with soil and firmed. An outer 4.5-foot square buffer infiltrometer surrounded the inner one to reduce the effects of lateral water flow (9).

Preceding the infiltration runs, hook gauges were positioned 3 inches above the soil surface in both the inner (test) and outer (buffer) infiltrometer boxes and water was ponded on plastic sheeting to the hook gauge depth in the test infiltrometer. When the runs began water was rapidly added to the buffer infiltrometer simultaneously with removal of the plastic sheeting from the test infiltrometer. Thereafter water was added frequently to maintain a nearly constant head. The volume of water required to return the head in the test infiltrometer to the 3-inch depth was measured with a domestic water meter at the following times in minutes: 5, 10, 15, 20, 30, 40, 50, 60, 80, 100, 120, 140, 180, 220, 260, and 300. Water used for the infiltration runs was obtained from a nearby irrigation canal. During the study, July through October, 1962, the electrical conductivity of this water averaged 1.40 mmho/cm with only minor variation.

While the infiltration runs were in progress duplicate soil samples were taken in the immediate vicinity of the infiltrometers by depth increments of 0 to 3, 3 to 6, 6 to 12, 12 to 18, 18 to 24, 24 to 36, 36 to 48, 48 to 60, and 60 to 72 inches. Particle size distribution, electrical conductivity of saturation extracts, cation-exchange capacity, and water saturation percentage were determined from composites of the two samples using the same procedures as in Part I (1). The antecedent moisture conditions were determined by gravimetric sampling.

Soil cores of 100 cc volume were obtained at the midpoints of the above-mentioned depth intervals. Bulk density and oven-dry porosity were determined on these cores. Holes made in obtaining the cores were extended and left open for determining the depth to the water table.

The elevation of saline and nonsaline soil profile pairs relative to each other was determined by survey, and the slope of the soil surface at each saline and nonsaline infiltration location was determined. Since in the relative elevations of saline and nonsaline pairs the member with lower elevation would, as the datum reference, have zero elevation 1 foot was arbitrarily added to each elevation to avoid zeros in the statistical computations.

The soil surface vegetal, tillage, and antecedent moisture conditions varied considerably from one infiltration site to another. These influences were avoided as much as possible by comparing properties of individual saline-nonsaline pairs and by taking the relation between duration of infiltration and infiltration rate into account in choosing infiltration criteria.

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Table 1—List of variables measured on saline-nonsaline soil profile pairs

Variable	Abbreviation	Unit
Cumulative intake, 0 to 300 minutes	CI	cm
Final intake rate	FIR	cm/hr
Electrical conductivity of saturation extract	ECe	mmho/cm
Oven-dry porosity	ODP	vol %
Bulk density	BD	g/cc
Slope	S	ft/100 ft.
Sand	SA	wt %
Silt	SI	wt %
Clay	CL	wt %
Saturation percentage (water)	SP	wt %
Cation-exchange capacity	CEC	meq/100 g
Exchangeable sodium percentage	ESP	meq %
Relative elevation	E	ft
Water table depth	WTD	ft

The Data Processing Center, College Station, Texas, performed the analysis of variance for each profile characteristic using the average of the values by one foot depth intervals to 6 feet as the profile value. The value of the surface foot was obtained from the measured values corresponding to the depths in the formula [(0 to 3) + (3 to 6) + 2(6 to 12)]/4 and of the second foot by averaging the values for the 12- to 18-inch and 18- to 24-inch depth intervals. Differences at the 0.95 probability level, between saline and nonsaline members of a field site pair, were identified from Duncan multiple range listings (4).

The variables used in the analyses reported are listed in Table 1 along with their abbreviations and units of measure.

RESULTS

Infiltration Relations

The infiltration curves are presented as saline and nonsaline profiles averages in Fig. 1. The data points are plotted at the midpoints of the time intervals of measurement. The vertical bars through experimental points are the standard errors of the means.

The data show that the saline and nonsaline profiles differ in infiltration rate at all times longer than 10 min after infiltration began. During the first 10 min the cumulative infiltration was significantly correlated with the ratio (antecedent moisture/water saturation percentage), with the ratio (field air porosity/oven dry porosity), and with clay content—all of the surface foot—but was not significantly correlated with the salinity (ECe) of the surface foot. Thus variables other than salinity determined the amount of water that entered the soil early in the infiltration determination.

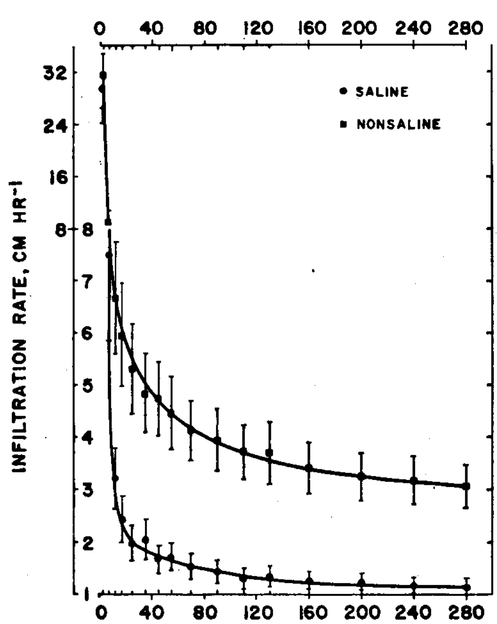

Fig. 1—Infiltration curves for saline and nonsaline profiles. Standard errors of the means are indicated by vertical bars.

Figure 2 presents the coefficients of determination, r^2, obtained from the correlation analysis of cumulative intake (cm water) for the time periods 10 to 300 min and 0 to 300 min with the infiltration rate at specific time intervals during the infiltration determinations. The results show that infiltration rate during any infiltration interval after the 5- to 10-min time interval is closely related to the cumulative intake during both the 0- to 300-min and 10- to 300-min periods. The relation continues to improve up to the 80- to 100-min infiltration interval then levels off in the case of the 10- to 300-min cumulative intake; the relation improves up to the 50- to 60-min infiltration interval for the 0- to 300-min cumulative intake then deteriorates slowly. Thus one has wide latitude in choice of infiltration criteria. For the analyses which follow the intake rate during the last infiltration interval, 260 to 300 min, designated the final intake rate (FIR) and cumulative intake during the 0- to 300-min infiltration interval (CI) will be used.

Saline-Nonsaline Profile Differences

Table 2 contains a summary of the results of Duncan multiple range tests for establishing the statistical difference between the dependent variables for saline-nonsaline profile pairs. Whether the particular attribute was greater in the saline or nonsaline profile, the number of times (frequency) it was greater, and the number of times the attribute differed significantly (0.95 level) from its paired member are given. The data show that in every saline-nonsaline profile pair the final intake rate (FIR) and the cumulative intake (CI) were statistically greater in the nonsaline member. The electrical conductivity of the soil saturation extract (ECe) and exchangeable sodium percentage (ESP) were greater in the saline profile and statistically different from the nonsaline profile values in every case. The clay percentage (CL) was greater and the ground surface elevation (E) was

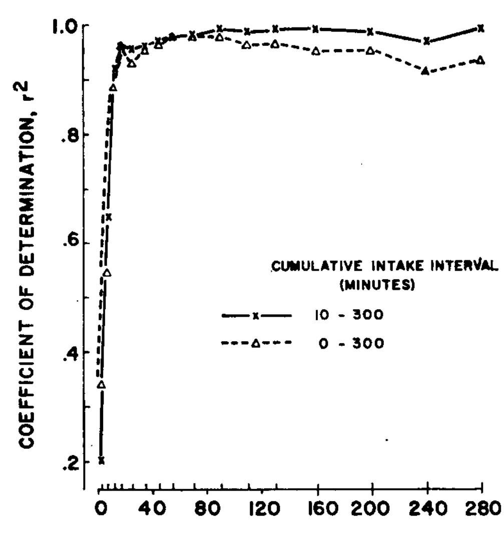

Fig. 2—Correlation between infiltration rate during specific time intervals and cumulative infiltration (cm water) during 10- to 300-min and 0- to 300-min time intervals.

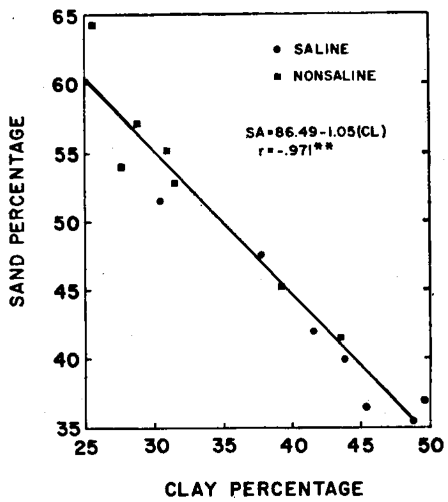

Fig. 3—Relation between clay content and sand content in saline and nonsaline profiles.

higher at the saline site in every case and statistically different from the nonsaline profile condition in 6 of the 7 cases. Sand percentage was greater in the nonsaline profile in every case and statistically greater in 5 of the 7 profile pairs.

The values for each profile and the average values of the saline and nonsaline profile characteristics most consistently different in the Duncan multiple range tests are presented in Table 3. It is evident that final intake rates in the nonsaline soils averaged nearly three times and cumulative intake twice those of the saline soils, that slopes are slight, and that saline soils are elevated relative to the nonsaline soils. The appreciable average electrical conductivity of the nonsaline profiles is attributable to the deeper soil depths since salinity generally increases with depth in the nonsaline profiles. (More detail on distribution of the salinity, exchangeable sodium percentage, clay percentage, and cation-exchange capacity with depth are given in a companion paper (1). The site numbers 1, 2, 3, 5, 6, and 7 of that paper are common to this study.)

The reciprocal relation between clay and sand percentage is shown in Fig. 3. The closeness of this relation implies that the range in weight percentage of silt in these profiles is very narrow. It also requires that sand and clay be correlated with the same profile characteristics.

Table 2—Results of Duncan multiple range tests summarized by saline-nonsaline pairs, 0- to 6-ft profile depth

Variable	Member of saline-nonsaline pair having larger value	Frequency	No. of times difference significant*
Cumulative intake, CI	Nonsaline	7	7
Final intake rate, FIR	Nonsaline	7	7
Electrical conductivity, ECe	Saline	7	7
Exchangeable sodium percentage, ESP	Saline	7	7
Clay percentage, CL	Saline	7	6
Relative elevation, E	Saline	7	6
Sand percentage, SA	Nonsaline	7	5
Slope, S	Saline	6	4
Cation-exchange capacity, CEC	Saline	6	4

* At 0.95 level.

Infiltration-Profile Characteristic Relations

The two-way table presented as Table 4 gives the simple correlation coefficients between a number of the variables of Table 3 which differed between saline and nonsaline profiles. Exchangeable sodium percentage (ESP) was deleted as a variable since it is highly significantly correlated ($r = .937$) with the electrical conductivity of the soil saturation extract (ECe). Even though the ESP of the saline soils is rather high, sufficient quantities of Ca^{2+} and Mg^{2+} are present to prevent dispersion during infiltration (1). Cation-exchange capacity (CEC) was deleted since it is a function of soil surface area which is adequately expressed by clay or sand percentage; it was significantly correlated with both. Slope (S) was highly significantly correlated ($r = .867$) with elevation (E) but not with any of the other variables.

The data of Table 4 show that profile salinity and both infiltration criteria are functions of sand, clay, and elevation. Both profile salinity and infiltration of water are more

Table 4—Simple correlation coefficients between several variables of Table 3 which differed between saline and nonsaline profiles (Correlation coefficients whose absolute value is ≥0.532 are significant at the 95% probability level and those ≥0.661 are significant at the 99% probability level)

	CL	E	EC_e	FIR	CI
SA	−0.971	NS	−0.659	0.746	0.717
CL	--	NS	0.588	−0.645	−0.643
E	--	--	0.734	−0.635	−0.531
EC_e	--	--	--	−0.720	−0.586
FIR	--	--	--	--	0.966

Table 3—Values by individual profiles and average values by saline and nonsaline categories of profile characteristics most consistently different in Duncan multiple range tests, 0- to 6-ft depth

Profile no.*	Sand content	Clay content	Relative elevation	EC_e	Final intake rate	Cumulative intake 0 - 5 hr	Slope	Exchange-able sodium	Cation-exchange capacity
	wt %	wt %	ft	mmho/cm	cm/hr	cm	ft/100 ft	meq %	meq/100 g
1	35.5	48.7	1.34	20.7	1.85	14.6	0.31	24.9	28.1
2	64.3	25.5	1.00	5.0	5.11	34.7	0.16	15.2	17.2
3	36.5	45.4	1.36	33.0	0.79	6.6	0.48	32.3	23.5
4	52.9	31.5	1.00	2.3	3.61	24.3	0.19	7.7	24.8
5	40.0	43.8	1.14	18.5	1.57	11.8	0.19	25.8	27.6
6	41.6	43.5	1.00	5.0	2.97	21.7	0.18	17.5	23.9
7	36.9	49.6	1.10	16.6	0.76	5.2	0.10	22.9	34.0
8	45.3	39.2	1.00	1.6	1.60	9.3	0.05	10.6	24.4
9	47.7	37.7	1.40	13.3	0.91	6.4	0.40	25.2	22.3
10	55.2	30.9	1.00	2.4	2.62	15.8	0.20	4.8	20.3
11	51.6	30.4	1.64	22.4	0.84	11.4	0.69	29.9	20.6
12	54.0	27.6	1.00	4.1	2.26	18.6	0.28	8.5	20.9
13	42.0	41.5	1.14	24.8	1.32	13.9	0.07	28.3	27.2
14	57.1	28.8	1.00	0.7	3.30	25.3	0.12	4.5	20.7
					Profile averages				
Saline	41.4	42.4	1.30	23.3	1.15	10.0	0.32	27.0	26.2
Nonsaline	52.9	32.4	1.00	3.0	3.06	21.4	0.17	9.8	21.7

* Odd numbered profiles are saline, even numbered ones nonsaline.

closely related to sand content of the profile than to clay content. Sand and clay content are not correlated with relative elevation. The data also show that both infiltration criteria are significantly correlated with soil salinity. Figure 4 presents the observed relation between ECe of the soil profile and final intake rate.

DISCUSSION

Interpretation of the significance and applicability of this investigation requires a knowledge of the problem area as well as consideration of the statistics presented. Soil (5, 2) and water table samplings (7) indicate that the source of salts is the saline fluctuating regional water table. The salts advance upward most rapidly in those areas highest in clay content. As shown in Table 3 the saline areas are, on the average, slightly elevated above the nonsaline areas and the slope of the soil surface at the saline areas generally exceeds that of the nonsaline areas.

The consequences of this combination of factors enable a feasible explanation for the occurrence of the salinity pattern observed. The naturally lower infiltration rates in the areas higher in clay content results in runoff of some o the rain which falls on these areas. The average elevation difference of 9 cm between saline and nonsaline sites in the same field also favors runoff from saline soils. Thus there is differential leaching between the saline and nonsaline areas. That rains sufficient to be effective in leaching do occur is evidenced by rainfall records for Raymondville, Texas, a reporting station representative of the problem area. Months of maximum 30-year normal rainfall are May and September with 3.48 and 4.65 inches, respectively (12). Thirty-year normal annual rainfall is 26.5 inches.

The differences in leaching are accentuated by the lack of a well-defined drainage pattern in the area. Heavy or intense rains cause ponding in the microtopographically lower nonsaline areas. Infiltration of the ponded water in the nonsaline areas further increases the difference in leaching that occurs between saline and nonsaline areas.

To recapitulate, differences in salinity appear to be due primarily to differences in leaching which in turn are influenced by relative ground surface elevations, the slope of the soil surface, and the soil infiltration rate. The infiltration rate varies with clay content of the soil. The elevation difference between saline and nonsaline areas in the same filed results in runoff of rainfall of intensities exceeding the infiltration rate of the soil. Since the salt-affected soil "islands" interspersed with nonaffected soil are narrow (5 to 100 m in width) and grade into the nonaffected soil areas the slopes are greater in the saline than nonsaline areas. This combination of clay content, elevation, and slope differences leads not only to the creation but also to the perpetuation of the observed salinity pattern.

Effective reclamation practices appear to be those that restrict runoff, enhance infiltration of rainfall, or reduce evaporative loss of moisture from the soil. Observation of fields which were leveled to zero grade several years ago indicates that land leveling alone is not effective in reclaiming the saline areas. Land leveling does not increase the infiltration rate of the saline areas, hence land leveling does not increase the leaching that occurs in the saline areas. Instead

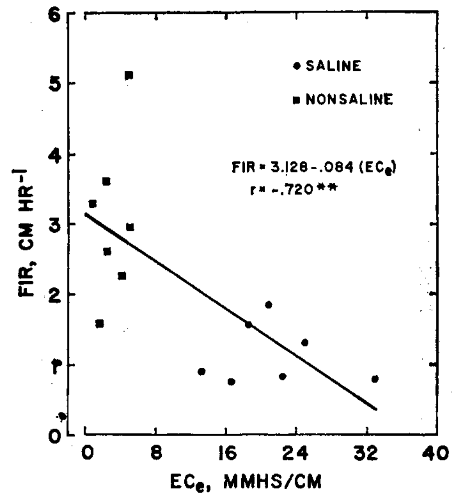

Fig. 4—Relation between profile salinity and final intake rate (FIR) in saline and nonsaline profiles.

they continue to act as contributing areas for nonsaline areas during high intensity storms. Cutting of the saline areas below the plane of the remainder of the field during leveling does look promising for increasing leaching of the saline areas. (Leon Lyles and R. R. Allen. Landforming for leaching of saline soils in a nonirrigated area. *Manuscript in preparation*). Use of vegetative mulches to reduce evaporation of soil moisture and to impede lateral surface flow has enhanced leaching under natural rainfall conditions (6).

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